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14. ABSTRACT
-Quarter-symmetric model is used in AutoDyn to simulate DoP experiments on aluminum targets and ceramic-faced aluminum targets with .30cal AP M2 projectile using SPH elements.
-Model validation runs were conducted based on the DoP experiments described in reference - ARL-TR-2219, 2000.
-Boundary conditions were modified in order to achieve better data agreement
-Further analysis will be conducted to determine the effect of material properties on DoP

15. SUBJECT TERMS
.30cal AP M2 Projectile, 762x39 PS Projectile, SPH, Aluminum 5083, SiC, DoP Expeminets, AutoDyn Simulations

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MONTHLY REPORT

AUGUST 2013

MODELING AND SIMULATION OF CERAMIC ARRAYS TO IMPROVE BALLAISTIC PERFORMANCE

MONTHLY REPORT FOR AUGUST 2013

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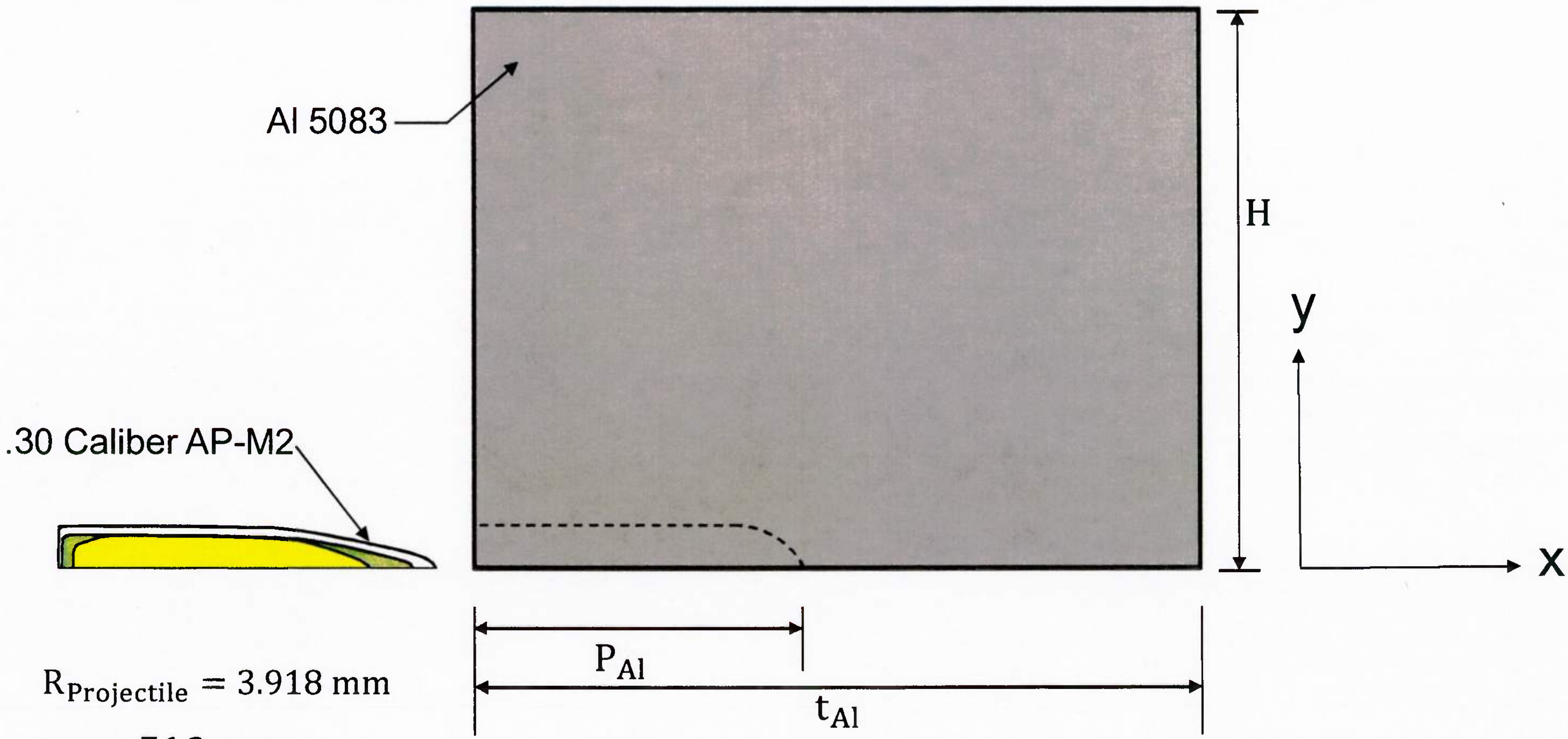
- Further analysis will be conducted to determine the effect of material properties on DoP

DOP OF .30cal PROJECTILE INTO MONOLITHIC ALUMINUM (Ref: ARL-TR-2219, 2000.)



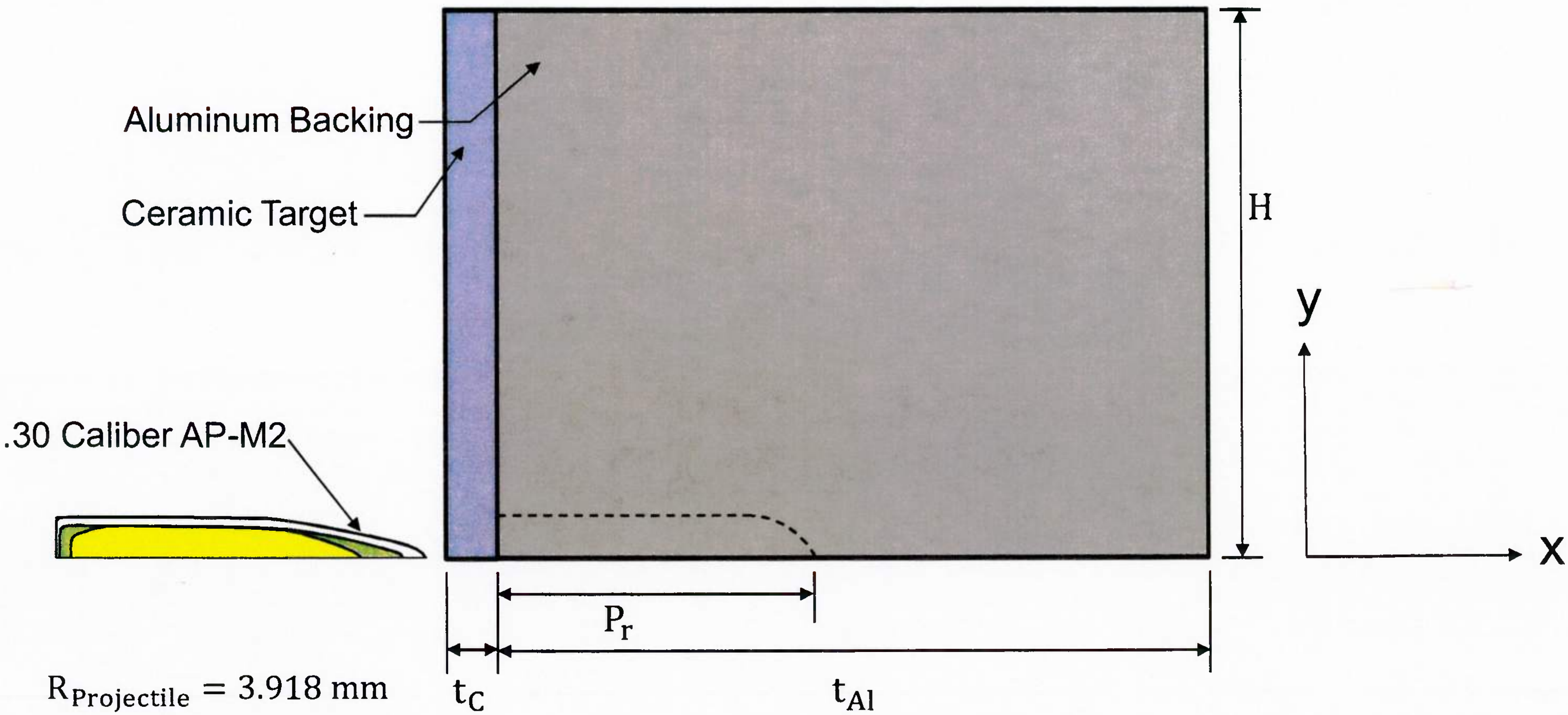
$R_{Projectile} = 3.918 \text{ mm}$

$t_{Al} = 76.2 \text{ mm}$

$H = 20.0 \text{ mm}$

$V_P = 400 - 900 \text{ m/s}$

DOP OF .30cal PROJECTILE INTO CERAMIC-FACED TARGET (Ref: ARL-TR-2219, 2000.)



$R_{Projectile} = 3.918$ mm

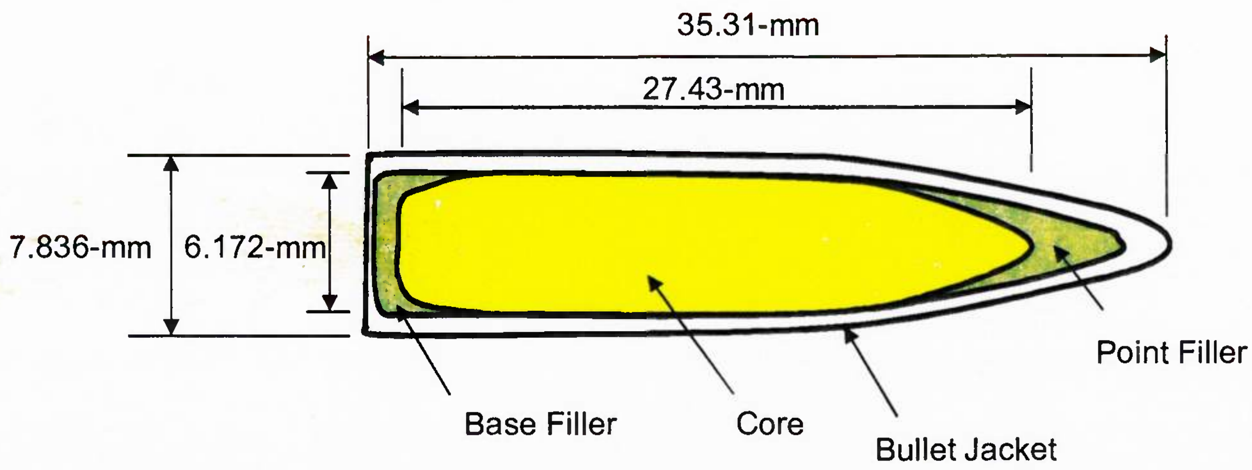
$t_C = 1.25, 2.50, 3.75, 5.00$ mm

$t_{Al} = 76.2$ mm

$H = 20.0$ mm

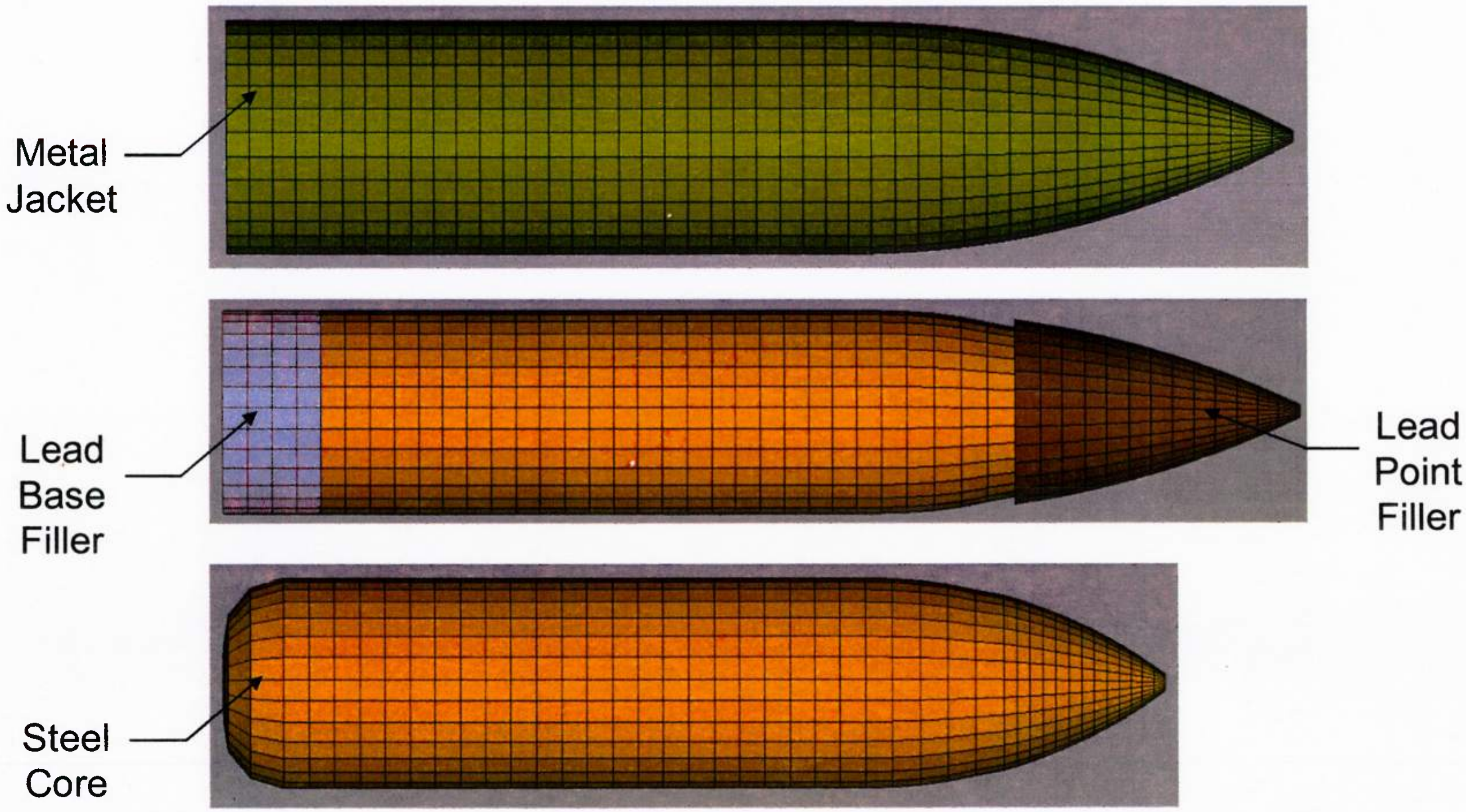
$V_P = 841 \pm 15$ m/s

30AP-M2 PROJECTILE MASS PROPERTIES



Component	Material	Weight (g)
Jacket	Gilding Metal	4.2
Core	Hardened Steel - RC 63	5.3
Point Filler	Lead	0.8
Base Filler	Lead	0.5
Total Weight		**10.8**

SOLID MODEL OF .30cal AP M2 PROJECTILE



MATERIAL PROPERTIES – Al 5083

Experimental Al 5083

	Al 5083
Density (g/cm^3)	2.65
Tensile Strength (MPa)	377.1
Yield Strength (MPa)	318.5
Elongation (%)	9.3

Ref:
MTL TR-86-14, 1986.
ARL-TR-2219, 2000.

AutoDyn Al 5083

Equation of State	**Linear**
Reference density	2.70000E+00 (g/cm3)
Bulk Modulus	5.83300E+11 (ubar)
Reference Temperature	2.93000E+02 (K)
Specific Heat	9.10000E+06 (erg/gK)
Thermal Conductivity	0.00000E+00 ( )
Strength	**Johnson Cook**
Shear Modulus	2.69200E+11 (ubar)
Yield Stress	1.67000E+09 (ubar)
Hardening Constant	5.96000E+09 (ubar)
Hardening Exponent	5.51000E-01 (none)
Strain Rate Constant	1.00000E-03 (none)
Thermal Softening Exponent	8.59000E-01 (none)
Melting Temperature	8.93000E+02 (K)
Ref. Strain Rate (/s)	1.00000E+00 (none)
Strain Rate Correction	1st Order
Failure	**None**
Erosion	**None**
Material Cutoffs	-
Maximum Expansion	1.00000E-01 (none)
Minimum Density Factor	1.00000E-05 (none)
Minimum Density Factor (SPH)	2.00000E-01 (none)
Maximum Density Factor (SPH)	3.00000E+00 (none)
Minimum Soundspeed	1.00000E-04 (cm/s)
Maximum Soundspeed (SPH)	1.01000E+20 (cm/s)
Maximum Temperature	1.00000E+16 (K)

MATERIAL PROPERTIES - SiC

Experimental SiC

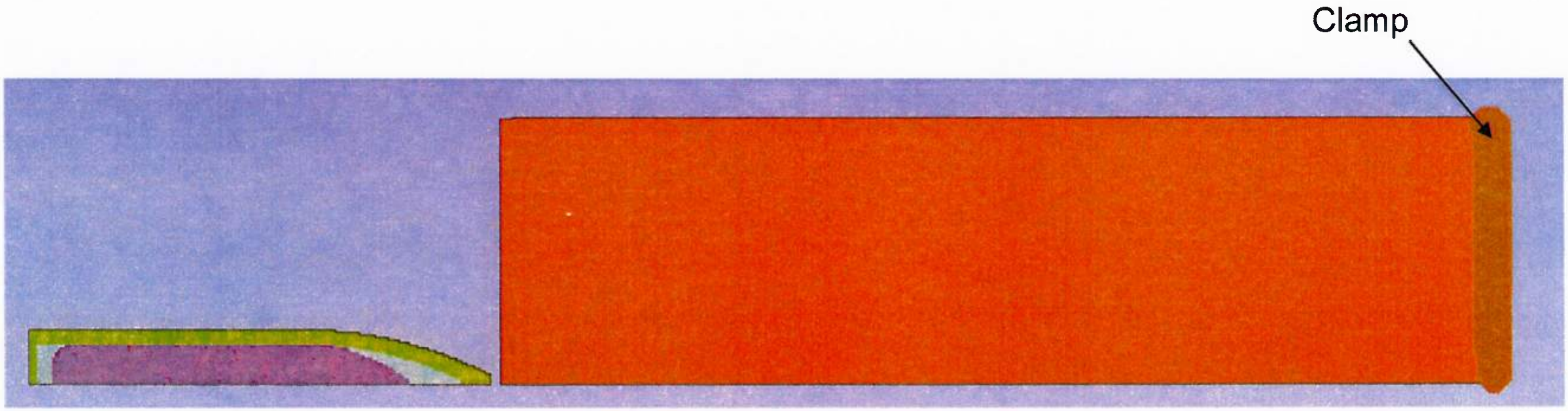
	SiC
Density (g/cm^3)	3.20
Elastic Modulus (GPa)	455
Shear Modulus (GPa)	195
Longitudinal Wave Velocity (km/s)	12.3
Poisson's Ratio	0.14
Hardness (kg/mm^2)	2700
Compressive Strength (MPa)	3410

Ref:
ARL-TR-2219, 2000.

AutoDyn SiC

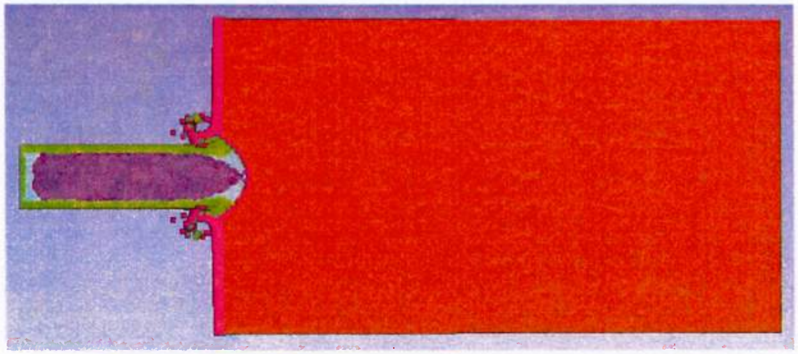
Equation of State	**Polynomial**
Reference density	3.21500E+00 (g/cm3)
Bulk Modulus A1	2.20000E+12 (ubar)
Parameter A2	3.61000E+12 (ubar)
Parameter A3	0.00000E+00 (ubar)
Parameter B0	0.00000E+00 (none)
Parameter B1	0.00000E+00 (none)
Parameter T1	2.20000E+12 (ubar)
Parameter T2	0.00000E+00 (ubar)
Reference Temperature	2.93000E+02 (K)
Specific Heat	0.00000E+00 (erg/gK)
Thermal Conductivity	0.00000E+00 ( )
Strength	**Johnson-Holmquist**
Shear Modulus	1.93500E+12 (ubar)
Model Type	Segmented (JH1)
Hugoniot Elastic Limit, HEL	1.17000E+11 (ubar)
Intact Strength Constant, S1	7.10000E+10 (ubar)
Intact Strength Constant, P1	2.50000E+10 (ubar)
Intact Strength Constant, S2	1.22000E+11 (ubar)
Intact Strength Constant, P2	1.00000E+11 (ubar)
Strain Rate Constant, C	9.00000E-03 (none)
Max. Fracture Strength, SFMAX	1.30000E+10 (ubar)
Failed Strength Constant, ALPHA	4.00000E-01 (none)
Failure	**Johnson Holmquist**
Hydro Tensile Limit	-7.50000E+09 (ubar)
Model Type	Segmented (JH1)
Damage Constant, EFMAX	1.20000E+00 (none)
Damage Constant, P3	9.97500E+11 (ubar)
Bulking Constant, Beta	1.00000E+00 (none)
Damage Type	Instantaneous (JH1)
Tensile Failure	Hydro (Pmin)

AUTODYN QUARTER-SYMMETRIC MODEL

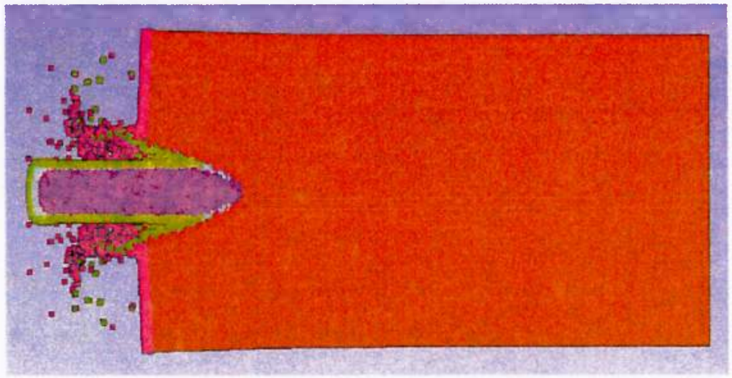


- Smoothed-particle hydrodynamics (SPH) used for all parts
- Target size = 0.50-mm totaling 351k elements
- Clamp boundary condition used at end of aluminum to secure the target

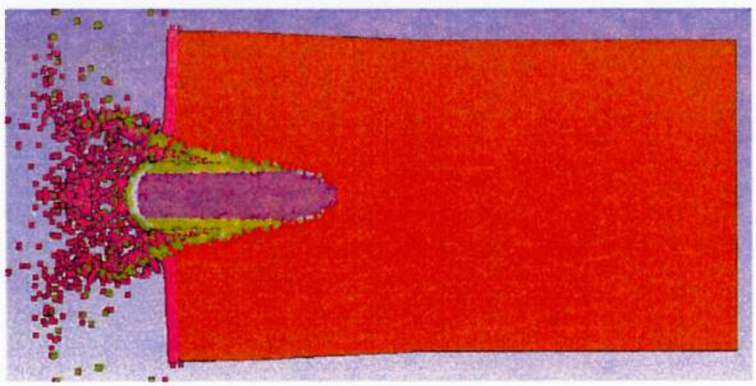
SHOT NO. 3002, V=834 m/s, t_c=1.25 mm



$t = 0.01587$ ms

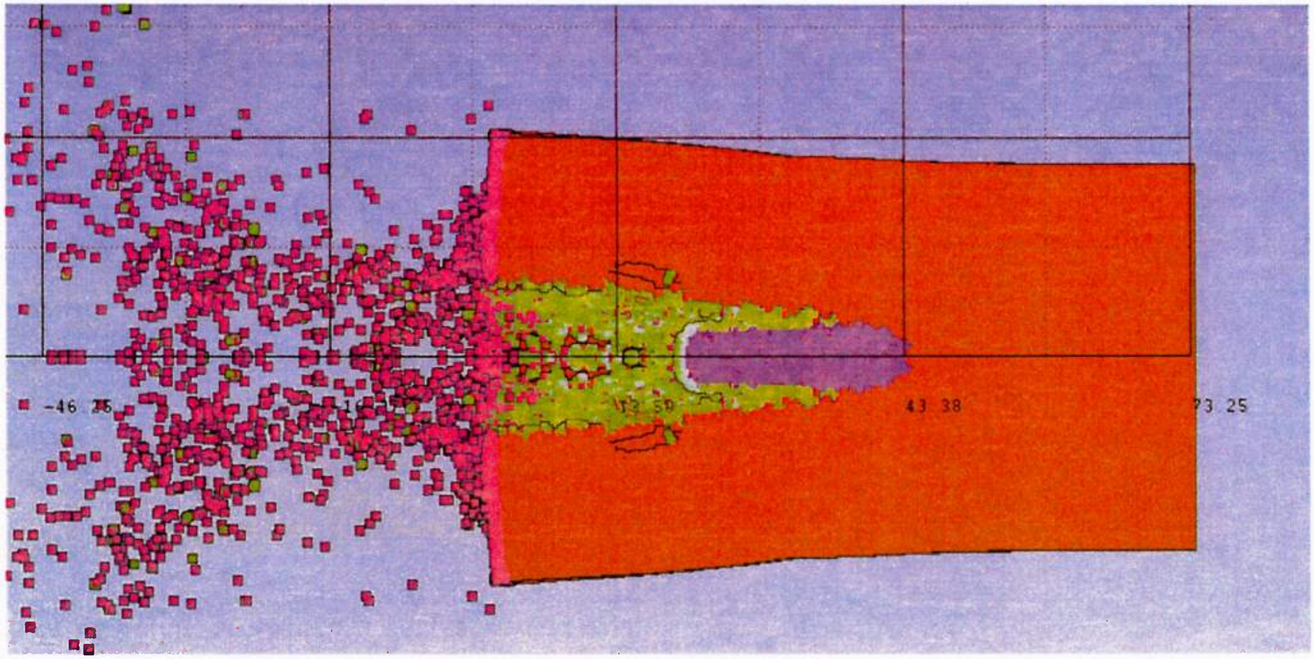


$t = 0.03314$ ms



$t = 0.04902$ ms

SHOT NO. 3002, V=834 m/s, t_c=1.25 mm

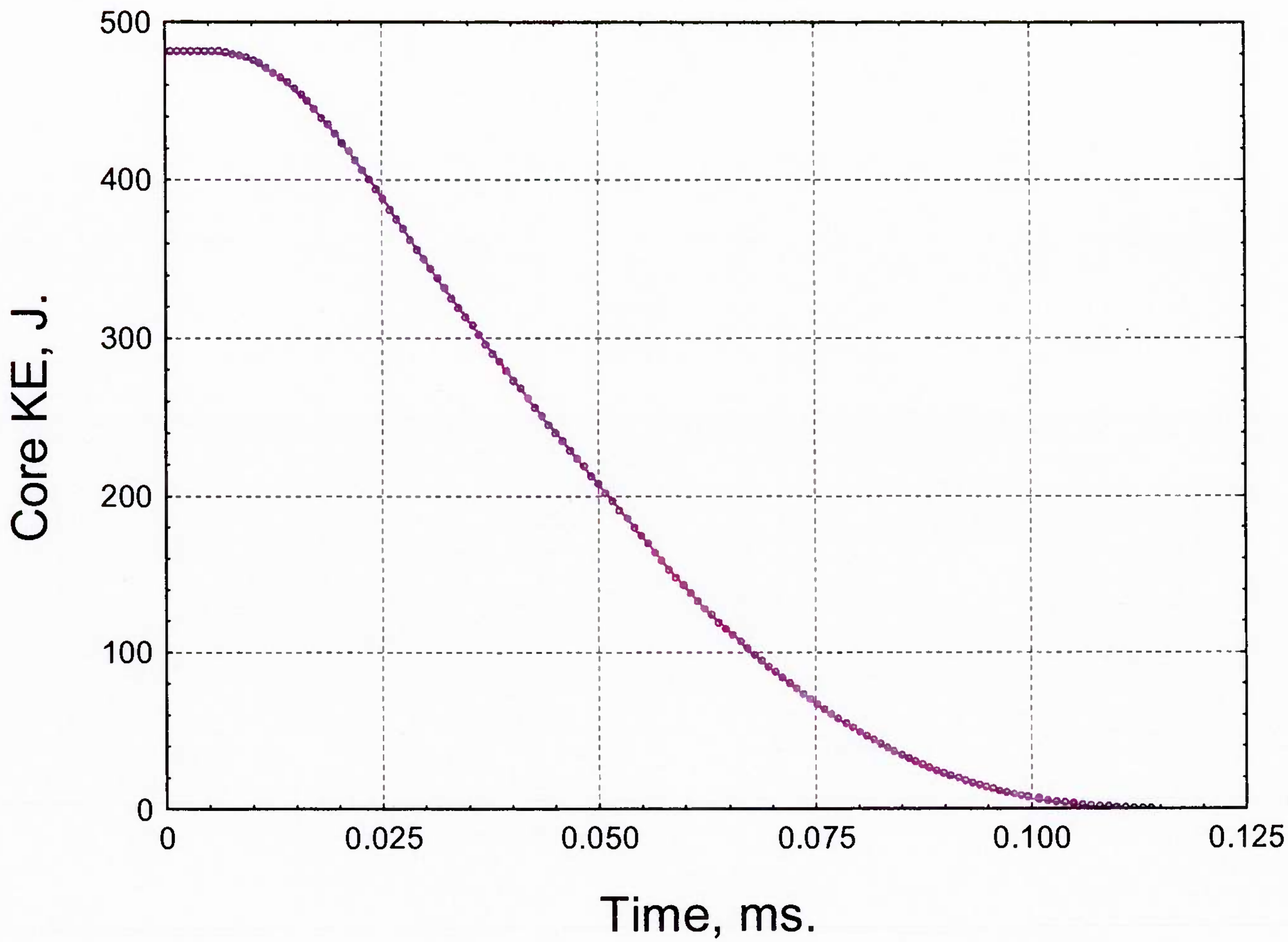


t = 0.1144 ms

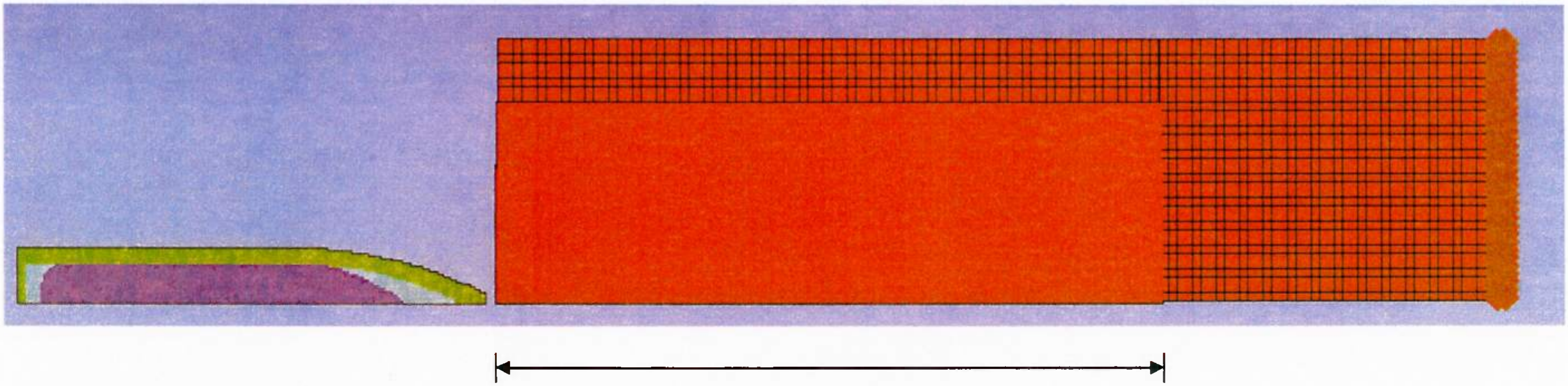
AutoDyn DOP = 43.38 mm

Experimental DOP = 40.1 mm

SHOT NO. 3002 PROJECTILE KINETIC ENERGY vs. TIME



QUARTER-SYMMETRIC AUTODYN MODEL

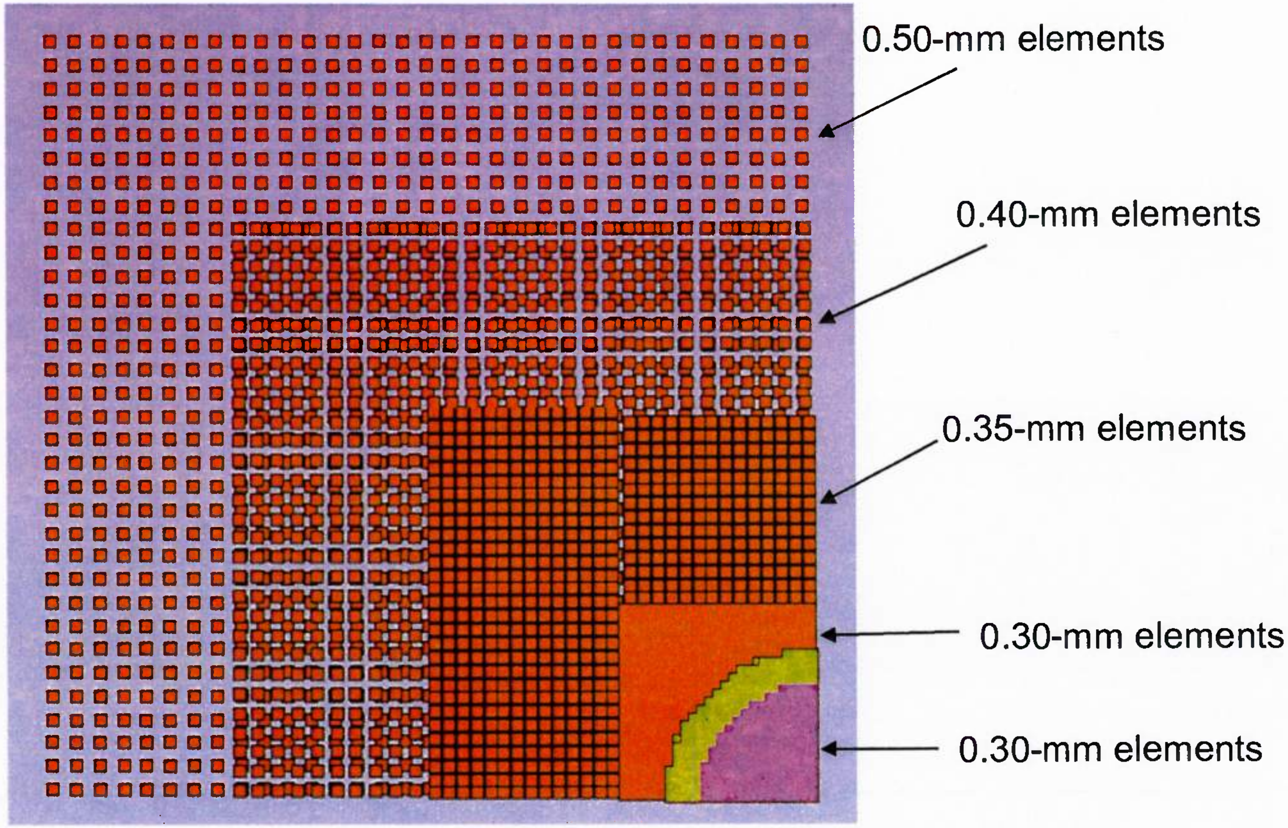


$L_{in} = 50$ mm

- ❑ Smoothed-particle hydrodynamics (SPH) used
- ❑ Element zoning necessary for computation
- ❑ Projectile and inside target zone element size = 0.30-mm
- ❑ 343k total elements
- ❑ Clamp boundary condition used at end of target

TARGET ELEMENT ZONING – FRONT VIEW

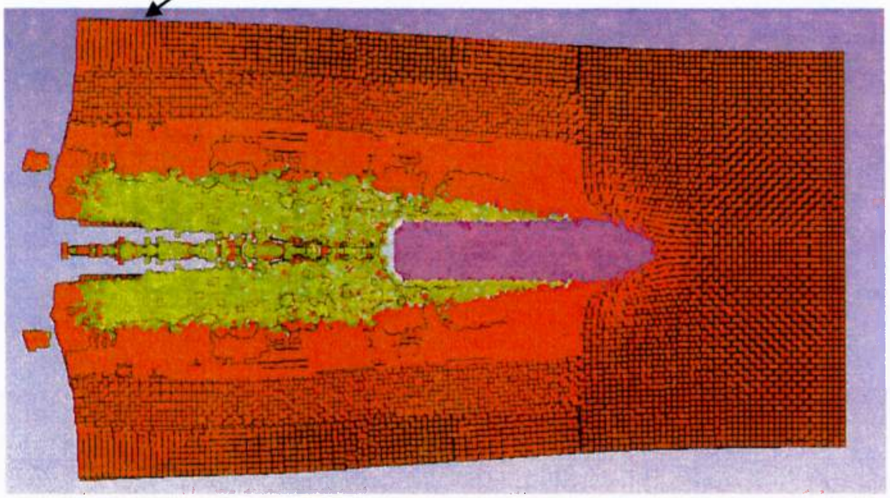
FRONT VIEW

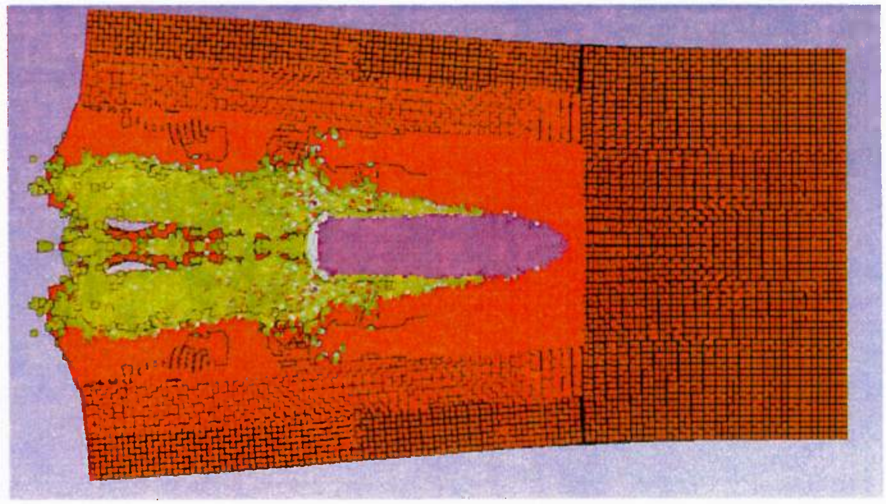


Total: 343k elements

SHOT NO. 2784, V=829 m/s

Large Deflection





Trial 1: Zoned Mesh Target

Trial 2: Increased Al yield strength (318.5 MPa)

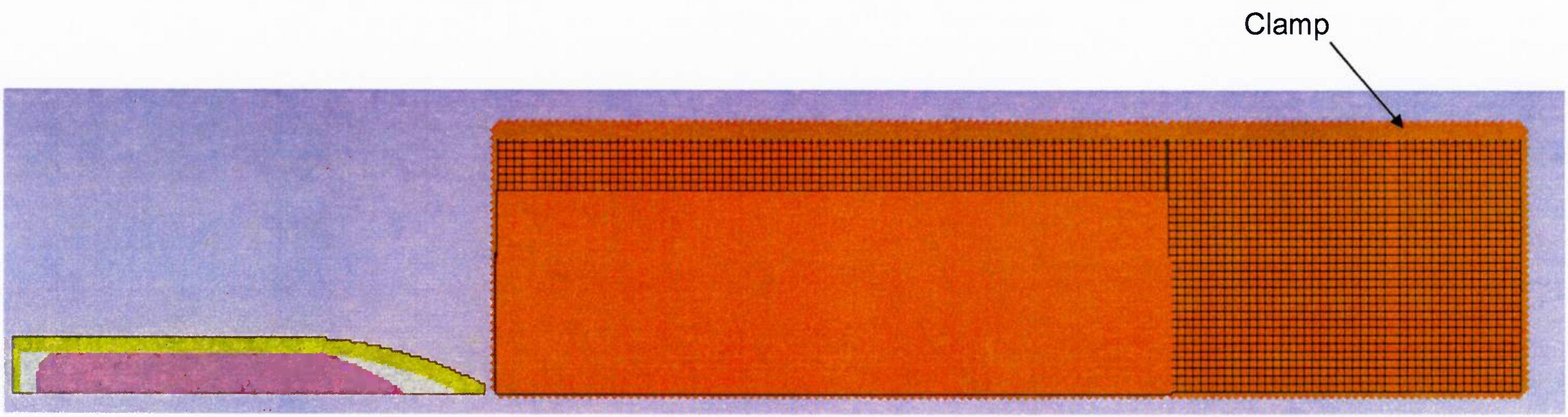
DoP = 56.75 mm

DoP = 50.93 mm

Literature DoP = 44.4 mm

Problem: Stress wave propagation at border creates large target deflections

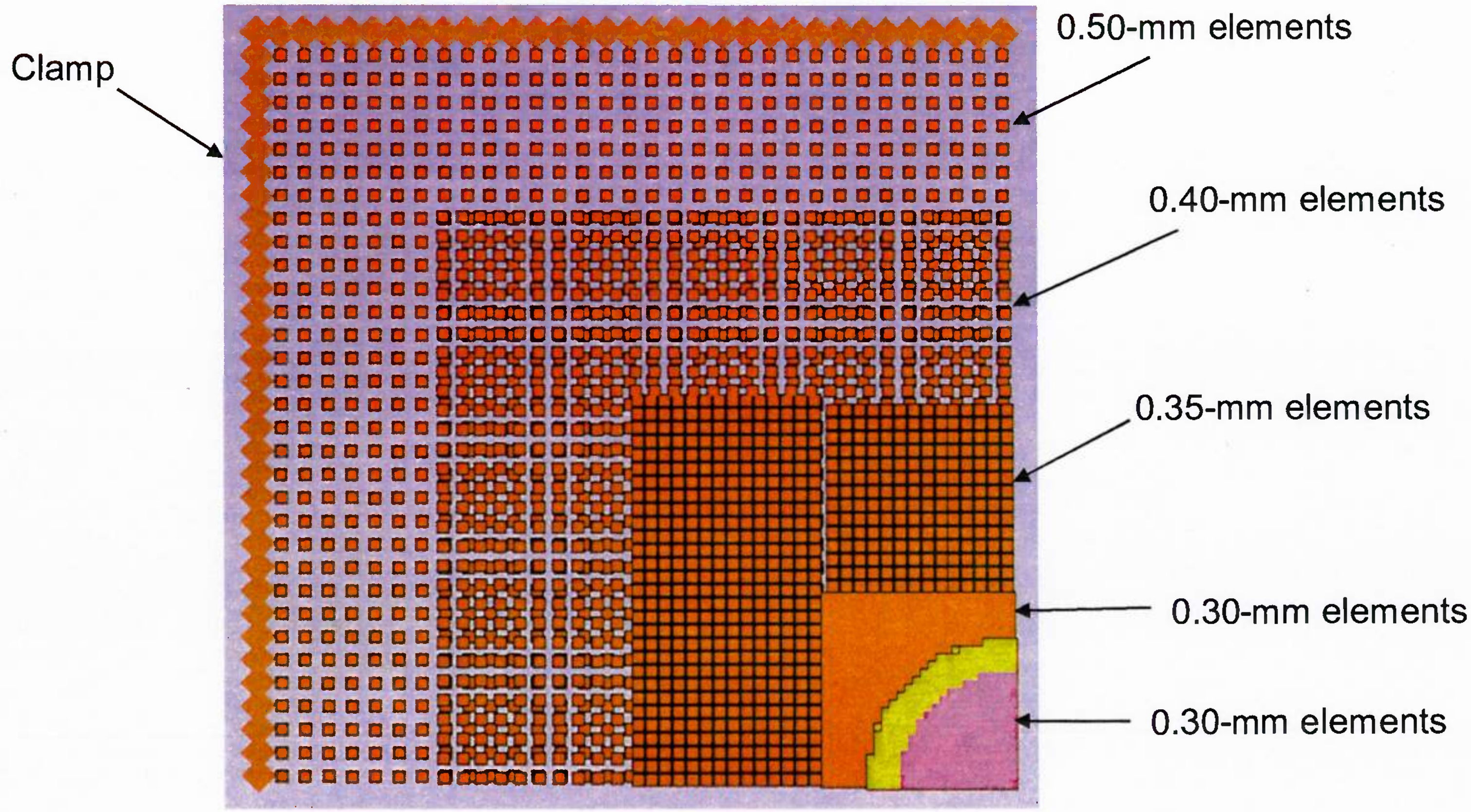
MODIFIED QUARTER-SYMMETRIC MODEL



Adding clamp boundary conditions to the outer faces of the target reduces the effect of the stress wave propagation on target failure

FULLY CLAMPED MODEL CROSS-SECTION

FRONT VIEW



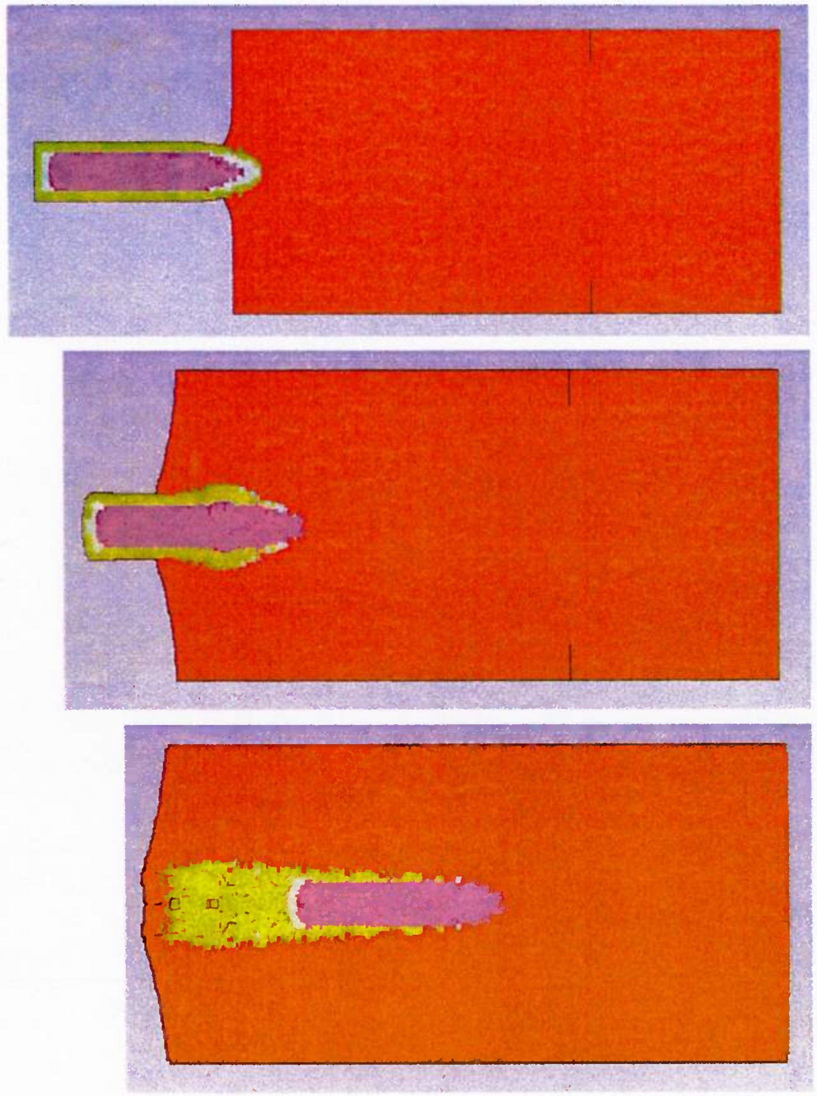
Total: 343k elements

SHOT NO. 2784, V=829 m/s

Measured DoP = 41.30 mm

Literature DoP = 44.40 mm

Uncertainty= 6.98%

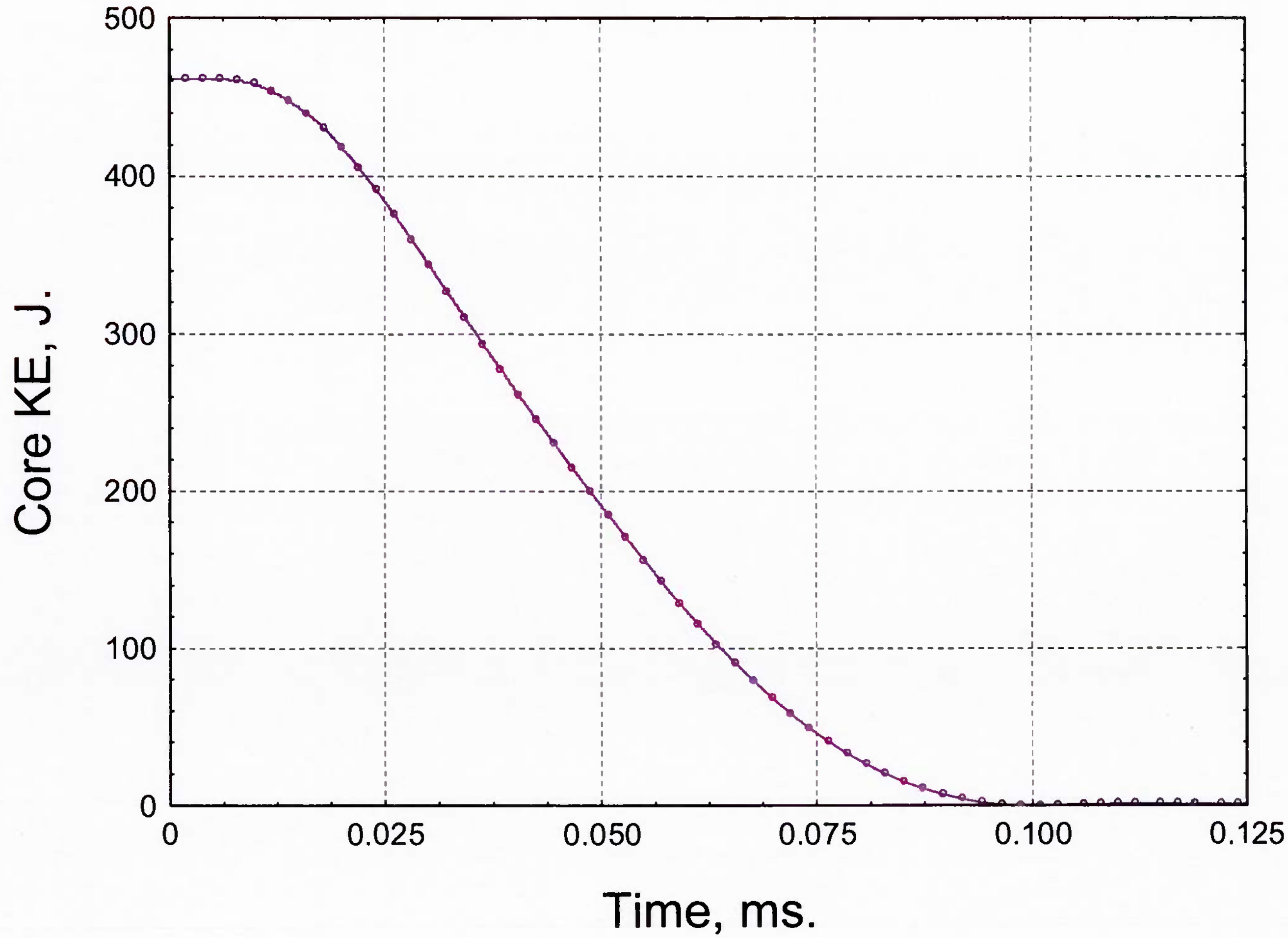


t = 0.010 ms

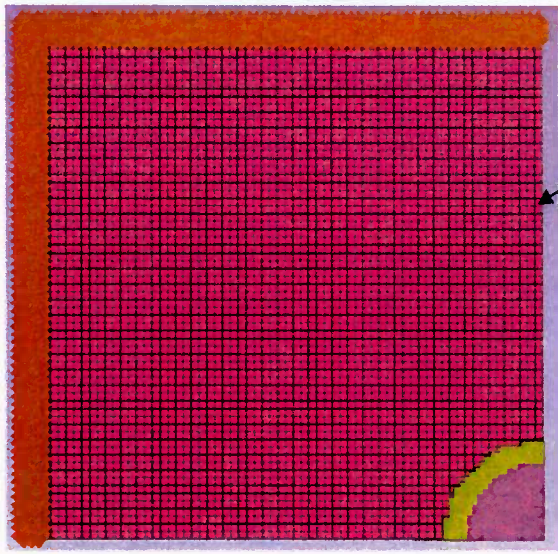
t = 0.022 ms

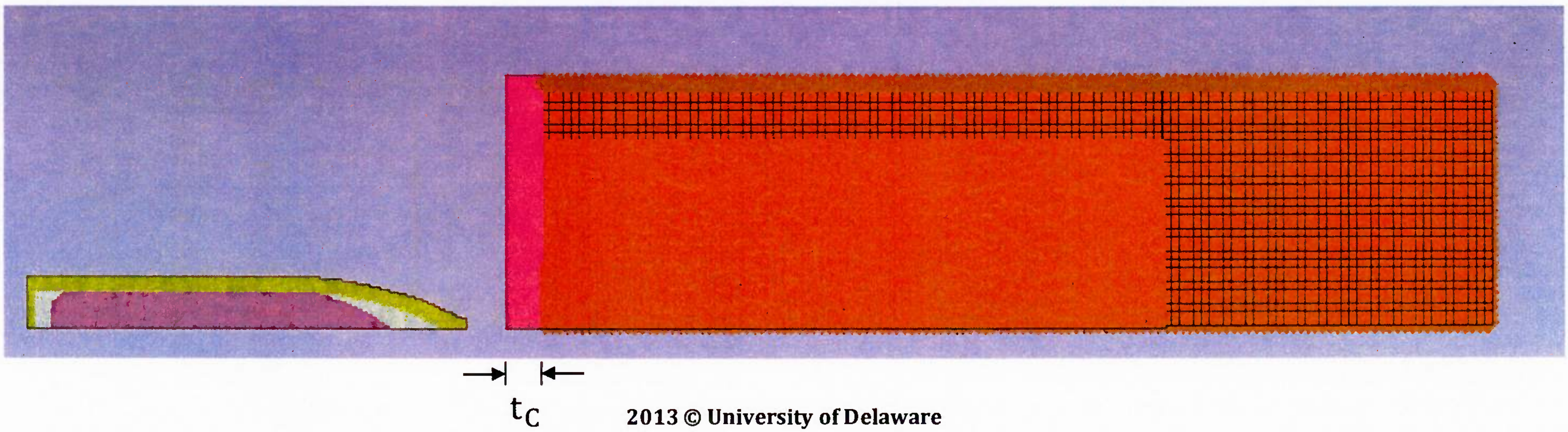
t = 0.101 ms

SHOT NO. 2784 PROJECTILE KINETIC ENERGY vs. TIME



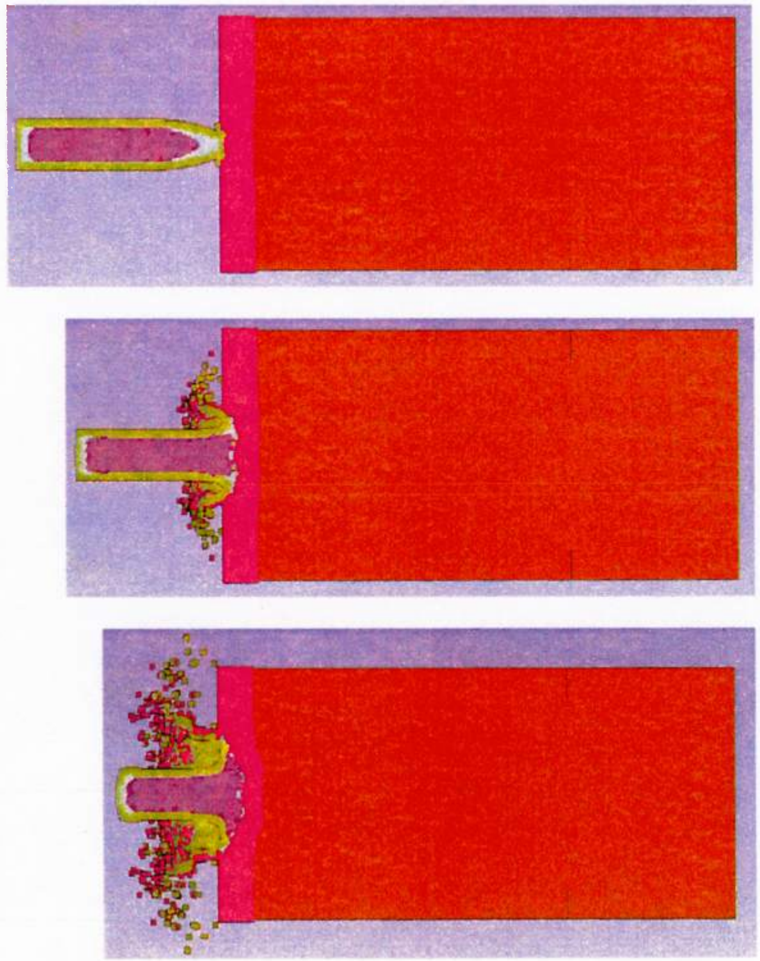
SHOT NO. 3048, V=829 m/s, t_c=5.08 mm





SHOT NO. 3048, V=829 m/s, t_c=5.08 mm

Projectile defeated in SiC tile, no DoP. Agrees with literature.

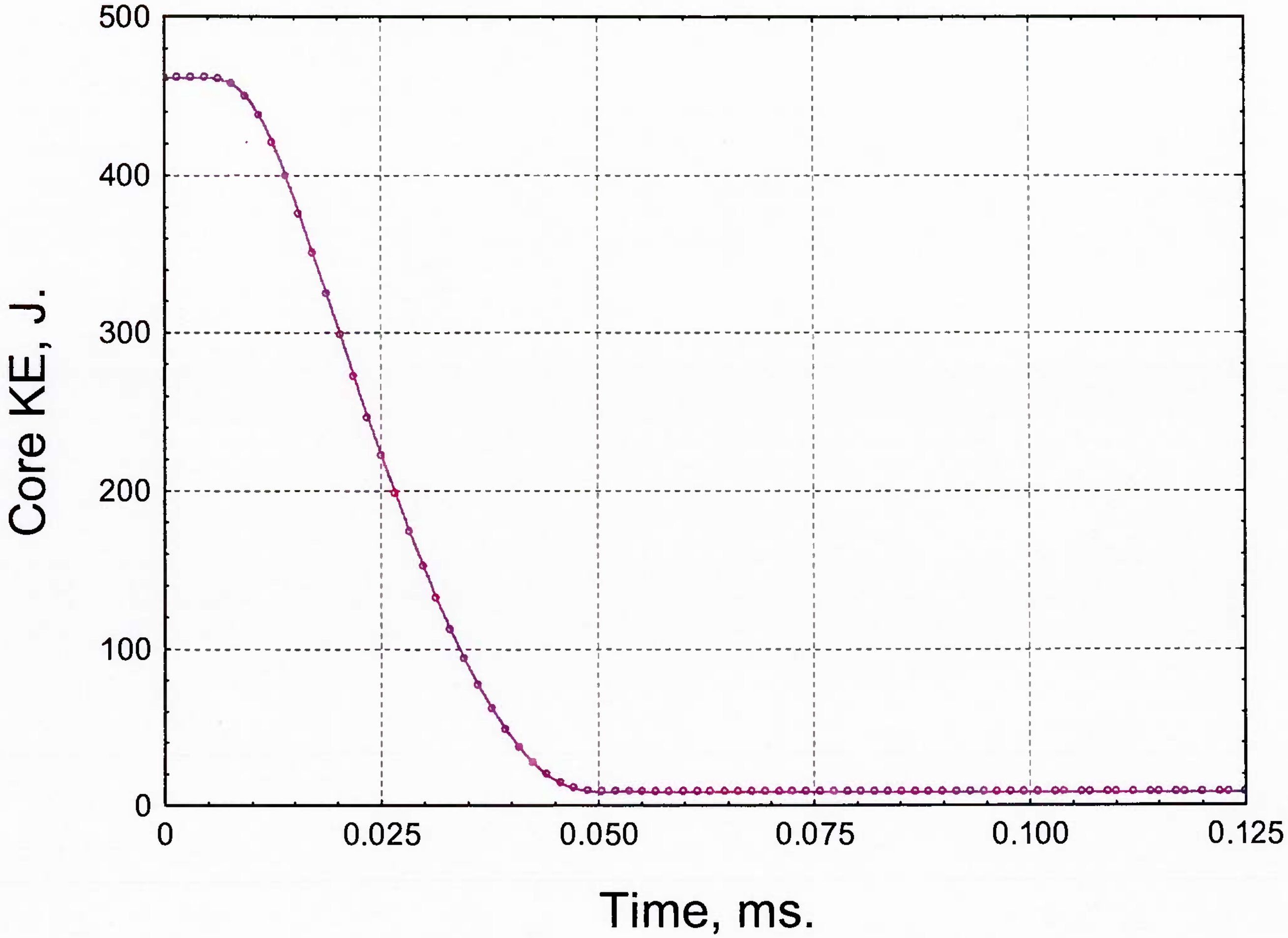


t = 0.0047 ms

t = 0.0025 ms

t = 0.0435 ms

SHOT NO. 3048 PROJECTILE KINETIC ENERGY vs. TIME



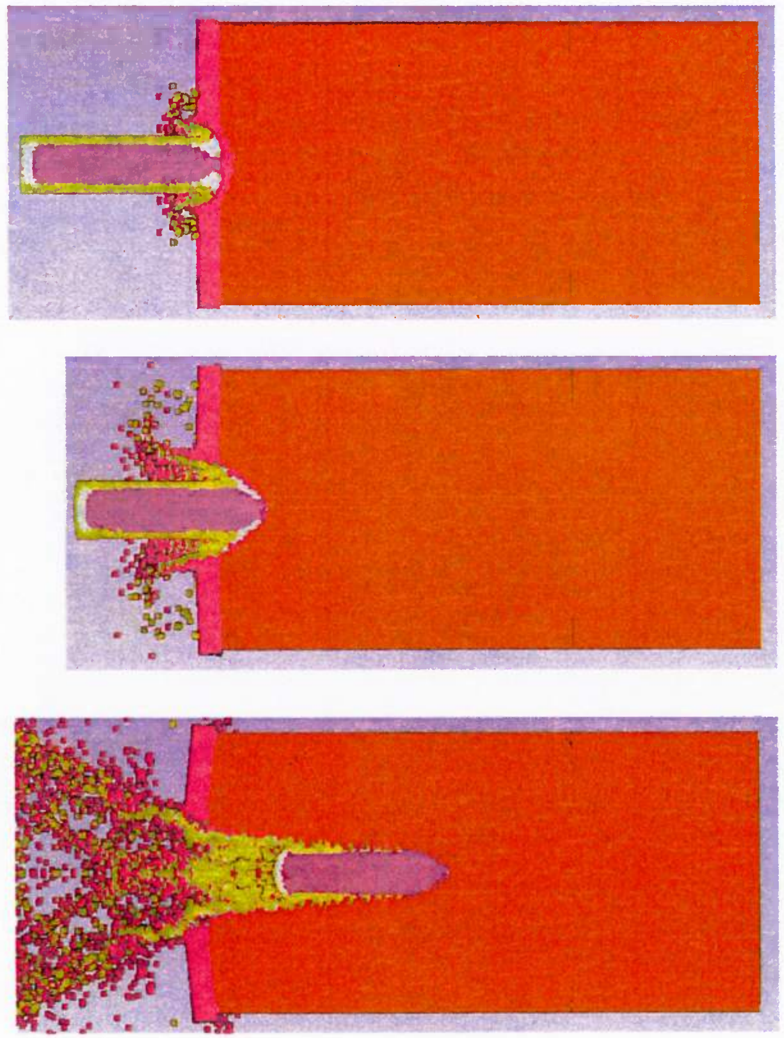
SHOT NO. 3005, V=843 m/s, t_c=2.59 mm

Measured DoP = 27.40 mm

Literature DoP = 22.80 mm

Uncertainty= 20.2%

Conclusion: Material properties of SiC may need to be adjusted to achieve better data agreement

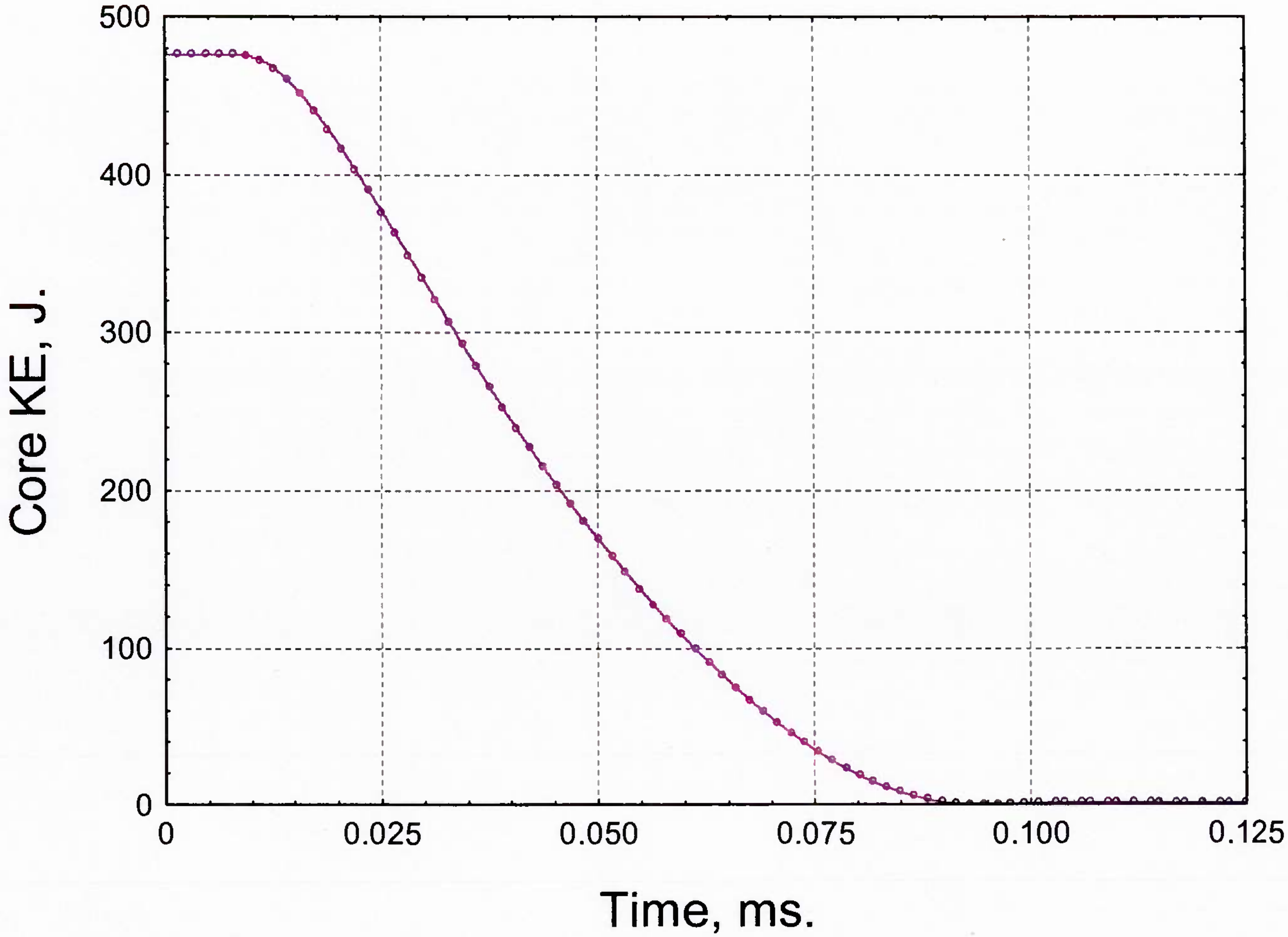


t = 0.016 ms

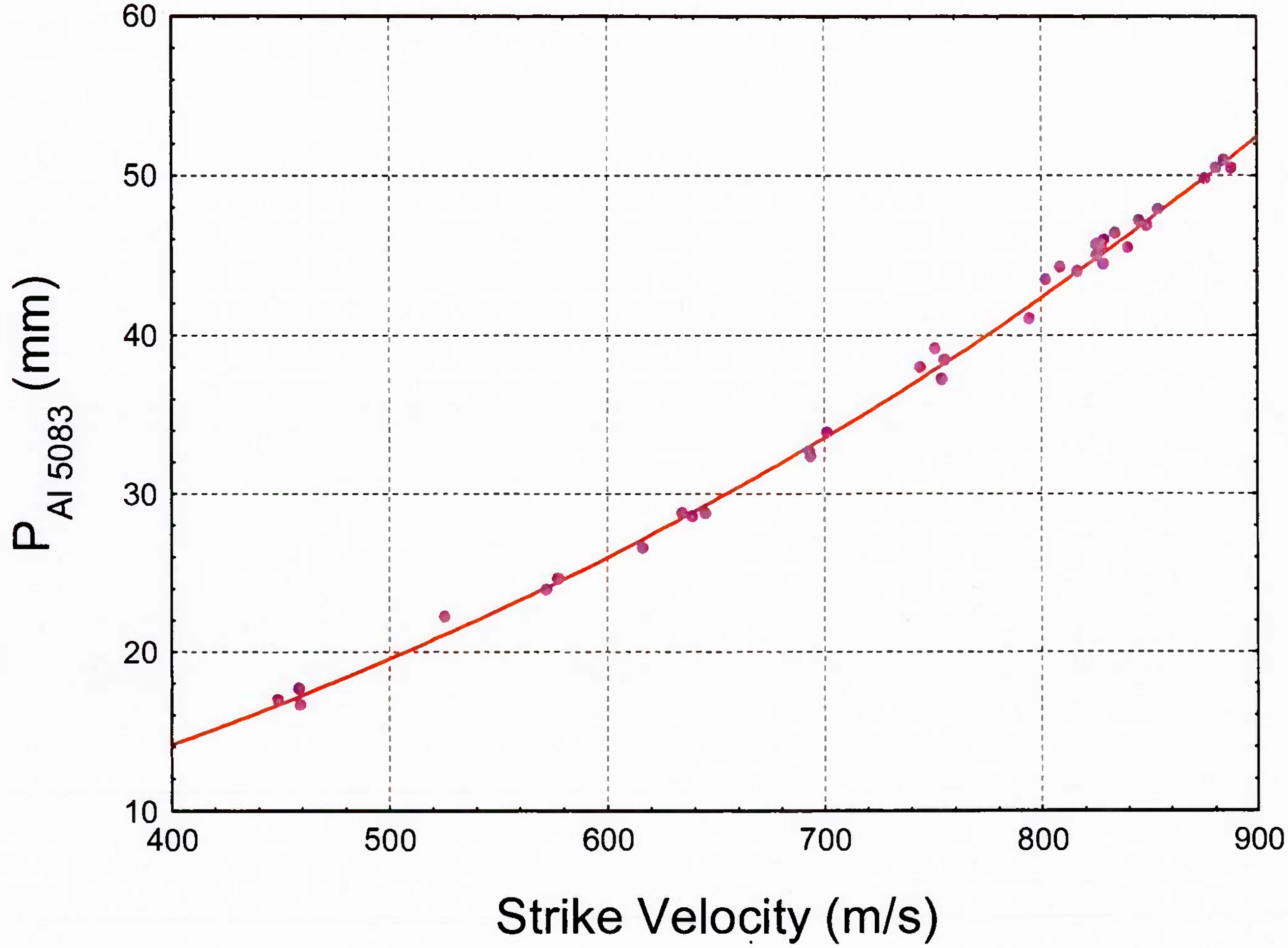
t = 0.025 ms

t = 0.101 ms

SHOT NO. 3005 PROJECTILE KINETIC ENERGY vs. TIME



PENETRATION INTO MONOLITHIC ALUMINUM vs. STRIKE VELOCITY (Ref: ARL-TR-2219, 2000.)



RESIDUAL PENETRATION AREAL DENSITY vs. CERAMIC AREAL DENSITY (Ref: ARL-TR-2219, 2000.)